Journal of Taibah University for Science 9 (2015) 564–569

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Synthesis of a new bis(perfluoroalkyl oxirane) dioxyethylene ether

Hayet Medini [a], Nejib Hussein Mekni [a,b,*], Ahmed Baklouti [b]

[a] *Chemistry Department, Faculty of Science & Arts, Al Ula Branch, Taibah University, Saudi Arabia*

[b] *Laboratory of Structural Organic Chemistry, Department of Chemistry, Faculty of Science of Tunis, University of Tunis, El Manar, 2092 Tunis, Tunisia*

Available online 1 November 2014

Abstract

Classic direct synthetic methods failed to transform bis(perfluororalkylallyl) dioxyethylene ether into the corresponding bis(perfluoroalkyl oxirane). This transformation was instead realized using a mixture of mercuric acetate/bromine to produce the corresponding bromoacetate, which was subsequently transformed to a bromohydrin and further to bis(perfluoroalkyl oxirane) through the use of triethylbenzyl ammonium chloride as a phase transfer catalyst in alkaline media.

Keywords: Bis(perfluoroalkylallyl) ethers; Perfluoroalkyl oxirane; Dialkene ethers; Epoxidation; Dioxirane

1. Introduction

Highly fluorinated compounds have been described as useful in a wide range of applications. They are commonly used as surfactants [1], agrochemicals [2], industrial chemicals [3], HIV anti-viral drugs [4], medically useful materials (*e.g.*, as blood substitutes) [5], pharmaceutical compounds [6] and biological agents [7]. Polyoxyethylene ethers are likewise known for their biological and medicinal uses [8,9] and especially for their biodegradable properties [10].

Oxirane compounds have been applied in a number of fields, including as pharmaceuticals [11], medicine [12], polymers [13], surfactants [14], and lubricants [15–17]. As these compounds are scientifically interesting, they have been used both as starting materials and as reaction intermediates in a number of different fields [18,19], such as polymer science [20], asymmetric synthesis [21], combinatorial chemistry [22], and microwave synthesis [23]. Their wide ranging importance across chemical sciences has cultivated a great interest in their syntheses [24] through routes using peracids [25], chlorate ions [26] halohydrins [27] or other catalytic methods [28]. Their structures [29,30] vary from simple [31] to asymmetric [32] or as complex systems [33].

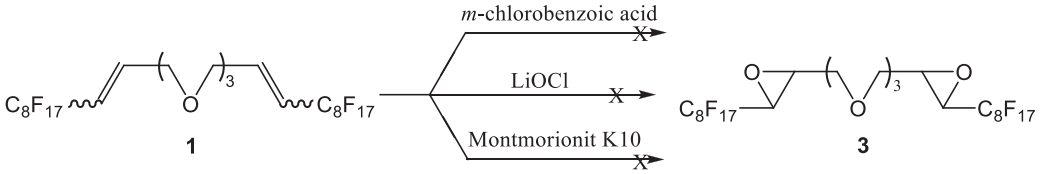
The preparation of perfluoroalkyl oxiranes [34] from perfluororalkene was first reported by Tarran et al. [35], after which a number of other methods appeared in the literature [36]. The lone direct epoxidation of perfluoroalkyl ethene was performed using a potentially hazardous mixture of H_2O, CH_3CN, and F_2 [37]. Indirect methods generally proceed through the initial synthesis of the corresponding bromoacetate using a mercuric

* Corresponding author at: Laboratory of Structural Organic Chemistry, Department of Chemistry, Faculty of Science of Tunis, University of Tunis, El Manar, 2092 Tunis, Tunisia. Tel.: +216 98904637.

E-mail address: n.mekni@gmail.com (N.H. Mekni).

Peer review under responsibility of Taibah University.

http://dx.doi.org/10.1016/j.jtusci.2014.10.001



Scheme 1. Failed direct epoxidation methods of bis(perfluoroalkylallyl) **1**.

acetate/bromine mixture in acetic acid [36(g)]. Different methods have been described for the following steps [36], but the best results were obtained in our laboratory, as reported by Chaabouni et al., using 50% aqueous sodium hydroxide in the presence of a phase transfer catalyst (PTC). The optimal system consisted of triethylbenzyl ammonium chloride and a mixture of organic solvents, such as Et_2O/CH_2Cl_2 [38].

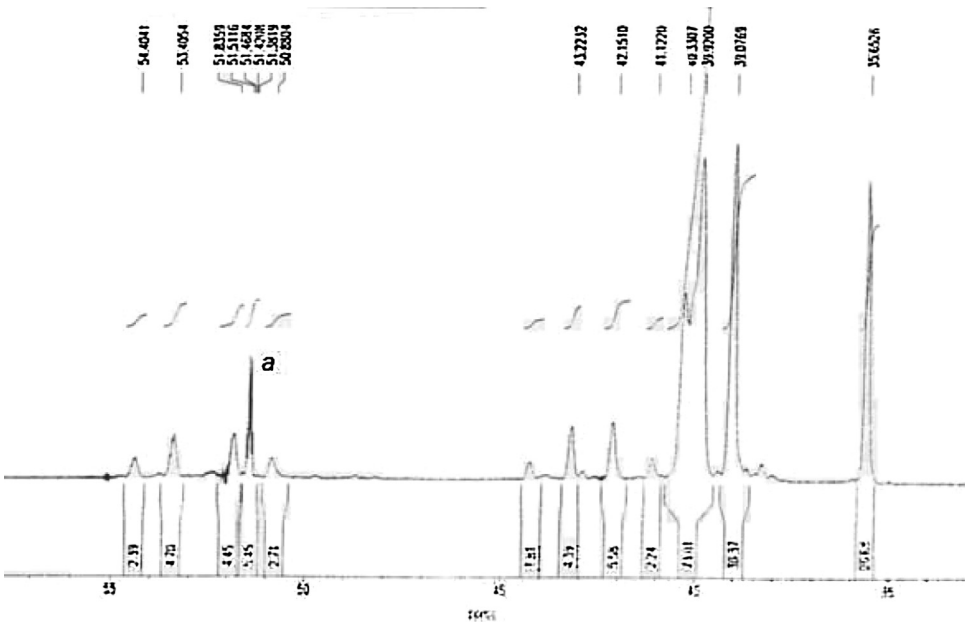
We have previously demonstrated the preparation of bis(perfluoroalkyl allyl) polyoxyethylene ethers [39]. As a continuation and in an attempt to synthesize the corresponding bis(perfluoroalkyl oxirane), we herein describe the synthesis of bis(heptadecafluoroalkyl oxirane) dioxyethylene ether.

2. Results and discussion

Addition reactions to bis(perfluoroalkyl allyl) dioxyethylene ether **1** are possible but require harsh conditions. For the synthesis of bis(perfluoroalkyl oxirane) **3**, we tested a number of direct epoxidation methods using *m*-chloroperbenzoic acid [40], lithium hypochlorite [41], and montmorionite K10 [42], but all of these methods failed to give the desired product (Scheme 1).

Therefore, we adopted an indirect method proceeding through the bromoacetate **2**, synthesized from bis(perfluoroalkyl allyl) dioxyethylene **1** in conjunction with a mixture of mercuric acetate/bromine

Scheme 2. Synthesis of (perfluoroalkyl bromoacetate) dioxyethylene **2**.



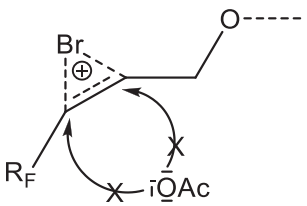
Scheme 3. ^{19}F NMR spectrum of (perfluoroalkyl bromoacetate) dioxyethylene **2**.

in acetic acid at room temperature (Scheme 2) [37]. The reaction was slow (15 days) and gave a low yield (35%), perhaps as a result of the low solubility of highly fluorinated **1** and its limited reactivity in addition reactions.

Starting from a mixture of *E*/*Z* isomers [39], only the *E* isomer of **1** was converted to the bromoacetate **2**. This synthetic step is non-stereoselective as the two faces of the ethylenic group are equivalent. The *EE* isomer of the bis(perfluoroalkyl allyl) dioxyethylene yielded the corresponding bromoacetate **2** as a mixture of diastereomers, which were identical by NMR.

In the ^{19}F NMR spectrum of bromoacetate **2**, the $CF_{2\alpha}$ fluorine atoms appear as an *AB* doublet cantered at −120.2 ppm and −110.3 ppm with $^{2}J_{FF} = 281$ Hz (Scheme 3). The *Z* isomer was unreactive, as confirmed in the ^{19}F NMR spectrum of the crude product showing a signal at −111.5 ppm, corresponding to the $CF_{2\alpha}$ of the allylic isomer *Z* (signal a, Scheme 3). The ^{1}H NMR spectrum of the unreacted isomer displayed a signal for the allylic proton.

Even after formation of the bromonium ion intermediate, back-side attack by the AcO^{-} anion is nearly impossible due to the steric bulk of the perfluoroalkyl and dioxyethylene chains present on the same side of the double bond in the *Z* form (Scheme 4).



Scheme 4. Forbidden addition of Br/OAc on the *Z* form of bis(perfluoroalkyl allyl) dioxyethylene **1**.

Use of the method previously described by Chaabouni *et al.* [38] allowed us to prepare bis(perfluoroalkyl oxirane) dioxyethylene **3** (Scheme 5). Bromoacetate **2** was converted to the corresponding bromohydrin using a 50% aqueous sodium hydroxide solution and was then transformed *in situ* to bis(perfluoroalkyl oxirane) dioxyethylene ether **3** by the addition of a PTC (triethylbenzyl ammonium chloride) in an equal-volume mixture of diethylic ether/dichloromethane. After stirring for 10 h, diepoxyde **3** was obtained in a 55% yield.

The new di(perfluoroalkyl oxirane) dioxyethylene ether **3** may have interesting physical and chemical properties as it bears two oxirane side groups, each capable of undergoing a large number of nucleophilic reactions.

Generalization of this reaction to other bis(perfluoroalkyl allyl) polyoxyethylenes **1** was not carried out due to the low yield of the first step, the long reaction time, and the lack of stereoselectivity in the synthesis of diepoxyde **3**.

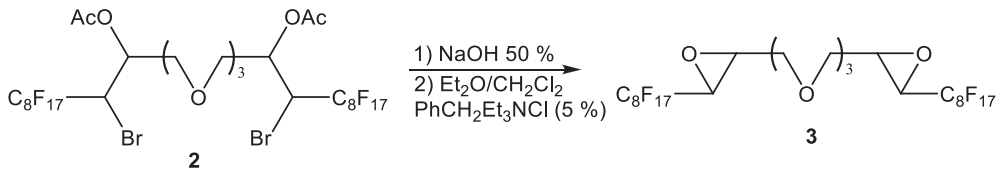
3. Conclusion

A new bis(heptadecafluoroalkyl oxirane) dioxyethylene was synthesized from the corresponding (perfluoroalkyl allyl) *via* a mixture of mercuric acetate/bromine followed by basic hydrolysis and cyclization in the presence of a PTC. Aside from the advantageous physical and chemical properties resulting from the perfluoroalkyl and polyoxyethylene chains, the presence of two oxirane groups on both sides provide the capacity for the di(perfluoroalkyl oxirane) dioxyethylene ether **3** to undergo a range of nucleophilic reactions. The syntheses of analogues of diepoxyde **3** from other perfluoroalkyl alkenes using different conditions are underway in our laboratory.

4. Experimental

4.1. Synthesis of bis(perfluoroalkyl bromoacetate) dioxyethylene 2

A mixture of 4.5 mL of acetic acid, 1.8 g of mercuric acetate and 0.5 mL of bromine were added to a 25-mL round bottom flask equipped with a condenser at 0 °C. Then, 3.5 mmol (3.58 g) of bis(3-perfluoroalkyl allyl) dioxyethylene **1** was slowly added. The mixture was stirred at room temperature for 15 days. At the end of the reaction, all solids were filtered and washed with water and ether. The filtrate was diluted in cooled water, washed with a solution of sodium thiosulfate, and decanted. The aqueous phase was extracted three times with ether after neutralization with a solution of



Scheme 5. Transformation of bis(perfluoroalkyl bromoacetate) **2** into the corresponding dioxirane **3**.

40% aqueous sodium hydroxide. The ether solutions were collected, neutralized with a carbonate potassium solution, and dried over sodium sulphate. After evaporation of the solvent, the residue was purified by column chromatography using a CH_2Cl_2/AcOEt 70/30 eluent to obtain compound **2** as a viscous oil.

IR $\nu_{C-F} = 1000–1050\,cm^{-1}$, $\nu_{C-O-C} = 1100–1120\,cm^{-1}$ and $\nu_{C=O} = 1735\,cm^{-1}$; ^1H NMR δ: 2.13 (s., 6H, $2CH_3$–), 3.40–3.90 (m., 4H, $2CH_2$-O), 3.65–3.85 (m., 8H, $4CH_2$-O), 4.53 (m., 2H, 2CHBr), 4.96 (m., 2H, 2CH-O); ^{13}C NMR δ: 18.5 (s., 2C, $2CH_3$-), 35.3 (m., 2C, 2CHBr), 69.1 (s., 2C, CH-O), 69.5 (s., 4C, $4CH_2$-O), 72.3 (s., 2C, CH_2-O), 105–120 (m., 16C, $16CF_2$, $2CF_3$), 161.2 (s., 2C, 2C=O); ^{19}F NMR δ: −127.2 (m., 4F, $2CF_2$), −123.8 (m., 4F, $2CF_2$), −123.0 (m., $2CF_2$), −122.6 (m., 8F, $4CF_2$), −120.2 and −110.3 (*AB syst*. 4F, $2CF_{2\alpha}$, $^2J_{FF} = 281$ Hz), −82.0 (m., 6F, $2CF_3$–, $^3J_{FF} = 10.97$ Hz) ppm.

4.2. *Synthesis of bis(perfluoroalkyl oxirane) dioxyethylene* ***3***

A solution of 2 g of sodium hydroxide in 2 mL of water was added to a two-neck 50-mL round bottom flask equipped with a condenser and a dropping funnel, which was placed on a magnetic stirrer prior to the addition of 0.8 mmol (1.04 g) of bis(perfluoroalkyl bromoacetate) dioxyethylene **2** at 0 °C. The reaction mixture was stirred for 5 h at room temperature, followed by heating to 40 °C. Vigorous agitation was necessary due to the thickening of the solution. After 5 h of stirring at 40 °C, the mixture was cooled to 0 °C and 4 mL of an equal-volume mixture of Et_2O/CH_2Cl_2 and 0.01 g of $PhCH_2N^+Et_3Cl^-$ (5%) were added. The mixture was stirred for 2 h at room temperature, filtered, washed, and extracted with ether (3 × 50 mL). The solvent was evaporated and the residue was purified by column chromatography using a CH_2Cl_2/AcOEt 80/20 eluent to obtain compound **3** as a viscous oil.

IR $\nu_{C-F} = 1000–1050\,cm^{-1}$, $\nu_{C-O-C} = 1100–1120\,cm^{-1}$; ^1H NMR δ: 3.45–3.60 (m., 6H, $2CH_2$ and 2CH), 3.65–3.76 (m., 8H, $4CH_2$-O), 3.92 (m., 2H, 2CH); ^{13}C NMR δ: 49.9 (m., 2C, CH-$CF_{2\alpha}$, $^3J_{C-F} = 27.52$ Hz), 58.5 (s., 2C, CH-O), 68.4 (s., 2C, CH_2O), 71.2 (s., 4C, CH_2O), 105–120 (m., 16C, CF); ^{19}F NMR δ: −123.0 (m., 4F, $2CF_{2\alpha}$), −123.9 (m., 4F, $2CF_{2\beta}$), −124.3 (m., 4F, $2CF_{2\delta}$), −124.9 (m., 4F, $2CF_{2\gamma}$), −127.3 (m., 4F, $2CF_{2\omega}$), −82.0 (6F, $2CF_3$, $^3J_{FF} = 10.36$ Hz) ppm; HRMS calculated 1054.04548, found 1054.04498.

Acknowledgements

The authors wish to thank the Tunisian Ministry of High Education and Scientific Research and Technology for financial support (LR99ES14) of this research, Dr. M.A.K. Sanhoury, MRSC from the Department of Chemistry, Faculty of Sciences of Tunis for technical assistance.

References

[1] (a) T. Schuster, S. Schellenberger, R. Friedrich, M. Klapper, K. Mullen, J. Fluor. Chem. 154 (2013) 30–36;
(b) N. Jaoued Grayaa, B. Boughariou-Charrada, A. Hedhli, J. Surfactants Deterg. (2013) 1–6;
(c) T. Kawase, T. Ankyu, T. Oida, Tenside, Surfactants Deterg. 49 (2012) 498–507;
(d) A. Khalfallah, B. Boughariou, A. Hedhli, J. Surfactants Deterg. (2012) 1–6.

[2] (a) F. Giornal, S. Pazenok, L. Rodefeld, N. Lui, J.-P. Vors, F.R. Leroux, J. Fluor. Chem. 152 (2013) 2–11;
(b) M. Khrizanforov, T. Gryaznova, O. Sinyashin, Y. Budnikova, J. Organomet. Chem. 718 (2012) 101–104;
(c) X.-D. Jiang, S. Matsukawa, K.-I. Kakuda, Y. Fukuzaki, W.-L. Zhao, L.-S. Li, H.-B. Shen, S. Kojima, Y. Yamamoto, Dalton Trans. 39 (41) (2010) 9823–9829.

[3] (a) N.O. Brace, S.G. Mull, J. Fluor. Chem. 127 (2006) 108–125;
(b) G. Gambaretto, L. Conte, G. Fornasieri, C. Zarantonello, D. Tonei, A. Sassi, R. Bertani, J. Fluor. Chem. 121 (2003) 57–63.

[4] (a) J.G. Riess, J. Greiner, Carbohydr. Res. 327 (2000) 147–168;
(b) M. Hocek, A. Holy, Collect. Czech. Chem. C 64 (1999) 229–241.

[5] A. Cambon, C.M. Edwards, R.P. Franke, K.C. Lowe, P. Reuter, W. Röhlke, H. Trabelsi, G.P. Gambaretto, M. Napoli, L. Conte, PCT Int. Appl., WO 1997, 49, 715; 128: 102340q.

[6] (a) S. Barata-Vallejo, A. Postigo, Coord. Chem. Rev. 257 (2013) 3051–3069;
(b) N. Oka, R. Murakami, T. Kondo, T. Wada, J. Fluor. Chem. 150 (2013) 85–91;
(c) S.D. Geiger, J. Xiao, A. Shankar, Am. J. Epidemiol. 177 (2013) 1255–1262;
(d) Z. Wang, T. Sun, J. Chen, H. Deng, M. Shao, H. Zhang, W. Cao, Tetrahedron 69 (2013) 4270–4275.

[7] (a) S. Bardhan, K. Kundu, B.K. Paul, S.K. Saha, Colloids Surf. A 433 (2013) 219–229;
(b) M.S. Sheikh, A.J. Khanam, R.-U.H. Matto, J. Kabir-Ud-Din, Surfactants Deterg. 16 (2013) 503–508;
(c) E.T. Maggio, Ther. Deliv. 4 (2013) 567–572;
(d) D. Selzer, M.M.A. Abdel-Mottaleb, T. Haha, U.F. Schaefer, D. Neumann, Adv. Drug Deliv. Rev. 65 (2013) 278–294.

[8] (a) D. Nowicka, D. Ginter-Kramarczyk, A. Holderna-Odachowska, I. budnik, E. Kaczorek, Z. Lukaszewski, Ecotox. Environ. Saf. 91 (2013) 32–38;
(b) G. Rauwel, L. Leclercq, J. Criquelion, J.-M. Aubry, V. Nardello-Rataj, J. Colloids Interface Sci. 374 (2012) 176–186;
(c) N. Mekni, A. Baklouti, J. Soc. Chim. Tunisie 11 (2009) 15–20.

[9] (a) J. Tang, Y. Wang, D. Wang, Y. Wang, Z. Xu, K. Racette, F. Liu, Biomacromolecules 14 (2013) 424–430;

(b) M. Hino, H. Ichihara, Y. Matsumoto, R. Ueoka, Biol. Pharm. Bull. 35 (2012) 2097–2101;
(c) S. Matsuda, M. Hisama, H. Shibayama, N. Itou, M.J. Iwaki, J. Oleo Sci. 58 (2009) 437–442;
(d) I. Mastouri, N. Mekni, A. Baklouti, J. Soc. Chim. Tunisie 11 (2009) 53–57.

[10] (a) N.H. Mekni, J. Fluor. Chem. 168 (2014) 75–80;
(b) Y.-I. Hsu, K. Masutani, Y. Kimura, T. Yamaoka, Macromol. Chem. Phys. 214 (2013) 1559–1568;
(c) Y.-Q. Sun, W.-J. Li, W.-X. Wang, Q.-X. Li, W. Hreczuch, W. Sulek, Tenside, Surfactants Deterg. 50 (2013) 9–13;
(d) M. Canciello, G. Maglio, G. Nese, R. Palumbo, Macromol. Biosci. 7 (2007) 491–499.

[11] (a) M. Mujahid, S.S. Kunte, M. Muthukrishnan, Teltrahedron Lett. 55 (2014) 3223–3226;
(b) Z. Tian, Y. Xiao, X. Yuan, Z. Chen, J. Zhang, J. Ma, Organometallics 33 (2014) 1715–1725.

[12] (a) V. Maier, C.M. Lefter, S.S. Maier, M. Butnaru, M. Danu, C. Ibanescu, M. Popa, J. Desbrieres, Mater. Sci. Eng. C 42 (2014) 243–253;
(b) S. Sarkar, R. Sonkar, G. Bhatia, N. Tadigoppula, Eur. J. Med. Chem. 80 (2014) 135–144.

[13] (a) C. Luo, J. Zuo, Y. Yuan, J. Zhao, High Perform. Polym. 26 (2014) 477–482;
(b) M. Anna, B. Tadeusz, N. Dorota, J. Polym. Res. 21 (2014) 1–13;
(c) J. Datta, E. Glowinska, J. Elastom. Plast. 46 (2014) 33–42;
(d) T. Zheng, Q. Zhou, Q. Li, L. Zhang, H. Li, Y. Lin, Solid State Ion. 259 (2014) 9–13.

[14] (a) S. Wirasate, C. Chokbunpiam, R. Thonggoom, P. Tangboriboonrat, J. Elastm. Plast. 46 (2014) 156–174;
(b) B. Darshak, M. Kalpana, P. Jigisha, J. Chem. Thermodyn. 74 (2014) 184–192;
(c) P. Pankaj, S. Arifa, A. Ishtiaque, J. Surfactants Deterg. 17 (2014) 253–260.

[15] A. Samaiah, K.V. Padmaja, R.B. Narayana Prasad, J. Oleo Sci. 63 (2014) 637–643.

[16] L. Elling, M.R. Kula, Biotechnol. Appl. Biochem. 13 (1991) 354–362.

[17] B. Kumar, N.S. Rathore, K.L. Ameta, Res. Chem. Intermed. 40 (2014) 555–567.

[18] (a) M. Ashwell, R.F.W. Jackson, J. Chem. Soc. Commun. (1988) 645–647;
(b) V.A. Petrov, Synthesis 15 (2002) 2225–2231.

[19] C.J. Whiteoak, A.H. Henseler, C. Ayats, A.W. Kleij, M.A. Pericas, Green Chem. 16 (2014) 1552–1559.

[20] (a) D.C. McLeo, N.V. Tsarevsky, Polym. Int. 63 (2014) 868–875;
(b) H. Zhang, M.W. Grinstaff, J. Am. Chem. Soc. 135 (2013) 6806–6809.

[21] (a) B. Barnych, B. Fenet, J.M. Vatele, Tetrahedron 69 (2013) 334–340;
(b) L.D. Nie, F.F. Wang, W. Ding, X.X. Shi, X. Lu, Tetrahedron: Asymmetry 24 (2013) 638–642.

[22] (a) F. Rostami-Charati, R.M. Hosseini-Tabatabaei, M. Shahraki, Comb. Chem. High Throughput Screen. 17 (2014) 35–37;
(b) T.J.L. Mustard, D.J. Mack, J.T. Njardarson, P.H.Y. Cheong, J. Am. Chem. Soc. 135 (2013) 1471–1475;
(c) S. Maruo, K. Nishio, T. Sasamori, N. Tokithoh, K. kuramochi, K. Tsubaki, Org. Lett. 15 (2013) 1556–1559.

[23] (a) J. Tharun, G. Mathai, A.C.K. Kattil, R. Roshan, J.Y. Kwak, D.W. Park, Green Chem. 15 (2013) 1673–1677;
(b) R. Sakhuja, K. Bajaj, S.M. Abdul Shakoor, A. Kumar, Mini-Rev. Org. Chem. 11 (2014) 55–72;
(c) Z. Hossaini, F. Rostami-Charati, S. Seyfi, M. Ghambarian, Chin. Chem. Lett. 24 (2013) 376–378.

[24] (a) V. Calo, A. Nacci, A. Monopoli, A. Fanizzi, Org. Lett. 4 (2002) 2561–2563;
(b) Z. Wang, J. Wen, Q. Wei Bi, X. Qi Xu, Z. Qing Shen, X. Xiao Li, Z. Chen, Tetrahedron Lett. 55 (2014) 2969–2972.

[25] (a) D. Mendez-Sanchez, N. Rios-Lombardia, V. Gotor, V. Gotor-Fernandez, Tetrahedron 70 (2014) 1144–1148;
(b) A.F. Zanette, I. Zampakidi, G.T. Sotiroudis, M. Zoumpanioti, I.C.R. Leal, R.O.M.A. de Souza, L. Cardozo-Filho, A. Xenakis, J. Mol. Catal. B: Enzym. 107 (2014) 89–94.

[26] (a) N. Saravanan, M. Sankaralingam, M. Palaniandayar, RCS Adv. 4 (2014) 12000–12011;
(b) T. Hashimoto, D. Hirose, T. Taniguchi, Angew. Chem. 126 (2014) 2768–2772;
(c) W. Kruse, Chem. Commun. (1968) 1610–1611.

[27] (a) J. He, J. Ling, P. Chiu, Chem. Rev. 136 (2014) 8911–8914;
(b) C. Siciliano, A. Barattucci, P. Bonaccorsi, M.L. DiGioia, A. Leggio, L. Minuti, E. Romio, A. Temperini, J. Org. Chem. 79 (2014) 5320–5326.

[28] (a) D. Limnios, C.G. Kokotos, J. Org. Chem. 79 (2014) 4270–4276;
(b) A. Decortes, M.M. Belmonte, J. Benet-Buchholz, A.W. Kleij, Chem. Commun. 46 (2010) 4580–4582.

[29] (a) L. Wang, T. Yoshida, M. Okamoto, Y. Sakihama, Y. Hashidoko, M. Hashimoto, Molbank M816 (2014) 1–3;
(b) J.K. Crandall, D.B. Banks, R.A. Colier, R.J. Watkins, J.P. Arrington, J. Org. Chem. 33 (1968) 423–425.

[30] (a) J.J. Feng, J. Zhang, J. Am. Chem. Soc. 133 (2011) 7304–7307;
(b) R.P. Unnikrishnan, S.-D. Endalkachew, S.V. Rajender, S. Varma, Tetrahedron Lett. 43 (2002) 2909–2911;
(c) P.M. Savu, J.A. Katzenellenbogen, J. Org. Chem. 46 (1981) 239–250.

[31] (a) M.J. Hatch, J. Org. Chem. 34 (1969) 2133–2137;
(b) F. Toda, N. Imai, J. Chem. Soc. Perkin Trans. 1 (1994) 2673–2674;
(c) Y. Hao, D. Xiaobing, C. Shengli, X. Jiaxi, Lett. Org. Chem. 8 (2011) 509–514.

[32] (a) E.N. Jacobsen, Acc. Chem. Res. 33 (2000) 421–431;
(b) J. Zanardi, C. Leriverend, D. Aubert, K. Julienne, P. Metzner, J. Org. Chem. 66 (2001) 5620–5623;
(c) M. Kumar, R.I. Kureshy, A.K. Shah, A. Das, N.H. Khan, S.H.R. Abdi, H.C. Bajaj, J. Org. Chem. 78 (2013) 9076–9084.

[33] (a) A. Dandia, R. Singh, S. Bhaskaran, Ultrason. Sonochem. 18 (2011) 1113–1117;
(b) T. Ling, B.C. Potts, V.R. Macheria, J. Org. Chem. 75 (2010) 3882–3885;
(c) V. Singh, Synlett 24 (2013) 2641–2659.

[34] (a) L.V. Saloutina, A.Y. Zapevalov, M.I. Kodess, P.A. Slepukhin, V.I. Saloutin, O.N. Chupakhin, J. Fluor. Chem. 139 (2012) 16–22;
(b) M.S. Fedoseev, L.F. Derzhavinskaya, V.I. Karmanov, D.N. Bahzin, A.Y. Zapevalov, T.I. Gorbunova, V.I. Saloutin, Russ. J. Appl. Chem. 83 (2010) 723–727;
(c) D.N. Bazhina, T.I. Gorbunovaa, A.Y. Zapevalova, I.V. Beketovb, V.I. Saloutina, Russ. J. Gen. Chem. 81 (2011) 1829–1833;
(d) D.N. Bazhin, T.I. Gorbunova, A.Y. Zapevalov, V.I. Saloutin, Russ. J. Org. Chem. 45 (2009) 491–495;
(e) V. Cirkva, J. Duchek, O. Paleta, J. Fluor. Chem. 121 (2003) 101–104;

(f) J.P. Begue, D. Bonnel-Delpon, A. Kornilov, Org. Synth. 75 (1998) 153–160;
(i) V. Cirkva, B. Améduri, B. Boutevin, O. Paleta, J. Fluor. Chem. 84 (1997) 53–61;
(j) V. Cirkva, B. Ameduri, B. Boutevin, O. Paleta, J. Fluor. Chem. 83 (1997) 151–158;
(k) P. Bravo, A. Mele, G. Salani, F. Viani, Bioorg. Med. Chem. Lett. 4 (1994) 1577–1580.

[35] P. Tarrant, E.G. Allison, K.P. Partholo, E.C. Stump, Fluor. Chem. Rev. 5 (1971) 77–113.

[36] (a) T.I. Ito, J. Kaufman, R.H. Kratzer, J.H. Nakamara, K.P.L. Paciorek, J. Fluor. Chem. 14 (1979) 93–103;
(b) D. Sianesi, A. Passeti, F. Tarli, J. Org. Chem. 31 (1966) 2312–2316;
(c) M.R. Brace, R.O. Chambers, J.R. Kirk, J. Chem. Soc. Perkin Trans. 1 (1984) 1391–1395;
(d) A.Y. Zapevalov, T.I. Filyakova, I.P. Kolenko, N.V. Peschanski, M.I. Kodess, Zh. Org. Khim. 20 (1984) 2267–2273;
(e) J.D. Park, F.E. Rogers, J.R. Lacher, J. Org. Chem. 26 (1961) 2089–2095;
(f) N.O. Brace, J. Org. Chem. 27 (1962) 3033–3038;
(g) C. Coudures, R. Pastor, A. Cambon, J. Fluor. Chem. 24 (1984) 93–104;
(i) R. Groth, J. Org. Chem. 25 (1960) 102–105;
(j) E.T. Mcbee, O.R. Pierce, W.H. Kilbourne, J. Am. Chem. Soc. 75 (1953) 4090–4091;
(k) V.A. Ponomarenko, A.M. Khomutov, N.A. Zadorozhnyi, B Acad. Sci. USSR CH+ 17 (1968) 1747–1751;
(l) J.B. Dickey, E.B. Towne, U. S. Pat., 2 700 686 (1956), Chem. Abst. 1956, 50, 5271c;
(m) I.L. Knunyants, E.Y. Pervova, V.V. Tyuleneva, B Acad. Sci. USSR CH+ 5 (1956) 863–869;
(n) E. Levas, A. Lecoq, Ann. Chim. 3 (1968) 529–532;
(o) B. Boutevin, J.P. Hugon, Y. Pietrasanta, J. Fluor. Chem. 17 (1981) 357–362.

[37] (a) S. Rozen, M. Brand, M. Kol, J. Am. Soc. 111 (1989) 8325–8386;
(b) S. Rozen, M. Kol, J. Org. Chem. 55 (1990) 5155–5159;
(c) M.H. Hung, B.E. Smart, A.E. Feiring, S. Rozen, J. Org. Chem. 56 (1991) 3187–3189.

[38] M.M. Chaabouni, A. Baklouti, S. Szonyi, A. Cambon, J. Fluor. Chem. 46 (1990) 307–315.

[39] N. Mekni, A. Hedhli, A. Baklouti, J. Fluor. Chem. 114 (2002) 43–46.

[40] (a) R.S. Porto, M.L.A.A. Vasconcellos, E. Ventura, Synthesis (2005) 2297–2306;
(b) N.K. Jana, J.G. Verkade, Org. Lett. 5 (2003) 3787–3790;
(c) N.N. Schwartz, J.-H. Blumbergs, J. Org. Chem. 29 (1964) 1976–1979.

[41] (a) P. Suresh, S. Srimurugan, R.T. Dere, R.V. Raga, S. Gopinath, Tetrahedron: Asymmetry 24 (2013) 669–676;
(b) A. Aghmiz, N. Mostfa, S. Iksi, R. Rivas, M.D. Gonzalez, Y. Diaz, F. El Guemmout, A. El Laghdach, R. Echarri, A.M. Masdeu-Bulto, J. Coord. Chem. 66 (2013) 2567–2577.

[42] W. Wenjuan, H. Jing, L. Shaoxiang, S. Daoxing, J. East China Norm. Univ. Nat. Sci. Ed. 43 (2013) 30–35.